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(54) Title: APPARATUS FOR SUPPORTING A SUBSTRATE AND METHOD OF FABRICATING SAME

(57) Abstract: Apparatus for protecting a substrate and a support surface of a substrate support chuck comprising a protective coating of a diamond-like carbon-based material deposited upon the support surface. The protective coating may also contain silicon-based materials. The protective coating is deposited via plasma-enhanced CVD and is approximately in the range of 1 - 5μm thick. The apparatus may also have a wafer spacing mask disposed upon the protective coating. A method of fabricating a substrate support chuck is also disclosed and comprises the steps of forming a chuck body having a support surface and depositing a carbon-based material over the support surface of said chuck body to form a protective coating. Optionally, a step of depositing a wafer spacing mask upon the protective coating may be added. The protective coating results in a substantial decrease in contamination of chucks, wafers and the process chamber environment.

APPARATUS FOR SUPPORTING A SUBSTRATE AND METHOD OF FABRICATING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to an apparatus for supporting a semiconductor wafer within a semiconductor processing system. More particularly, the invention relates to a substrate support having a protective coating and method of fabricating same, disposed upon a surface of the substrate support chuck.

2. Description of the Background Art

Substrate support pedestals are widely used to support substrates within process chambers of semiconductor processing systems. A particular type of pedestal used in semiconductor processing systems such as physical vapor deposition (PVD) is a ceramic electrostatic chuck. Such chucks are used to retain semiconductor wafers, or other workpieces, in a stationary position during processing. Such electrostatic chucks contain one or more electrodes embedded within a ceramic chuck body. The ceramic chuck body is, for example, fabricated of aluminum-nitride or boron-nitride or alumina doped with a metal oxide such as titanium-oxide or chromium-oxide or some other ceramic material with similar resistive properties. This form of ceramic may also be classified as a leaky dielectric as it becomes partially conductive at high temperatures.

In use, a wafer rests against a support surface of the chuck body as a chucking voltage is applied to the electrodes. The wafer is retained against the ceramic support by creating a return path for the chucking voltage through the wafer. That is, the electrodes and wafer are oppositely biased and insulated from each other via the chuck body. As such, equal and opposite electrostatic forces pull the wafer to the support surface.

One disadvantage of using a chuck body fabricated from ceramic is that the characteristics of the support surface change over time. During processing, the support surface is exposed to organic material. Specifically, water and hydroxides collect on the support surface. Such contaminants enter the chamber during wafer processing as wafers are passed from a loadlock to the chamber or when the chamber is exposed to the atmosphere during a maintenance cycle. Other contaminant sources may be photoresist or spin-on-glass coating remnants used during previous wafer processing steps. Additionally, outgassing of chamber components produces hydrocarbon contaminants, e.g., O-rings inside the chamber breakdown and outgas. These contaminants react and form a conductive contaminant film on the support surface. After repetitive processing and/or maintenance cycles, the conductive contaminant film grows on the support surface to the point where it degrades chuck performance. Similarly, ceramic substrate support chucks that are used in low temperature processing (e.g., less than 300°C) are also prone to such support surface contamination and degradation of chuck performance over long periods of time (e.g., approximately six months of use).

Another disadvantage of using a chuck body fabricated from a ceramic material is realized during manufacture of the chuck. Specifically, the sintering process used to fabricate a ceramic chuck results in "grains" of ceramic material that can be easily "pulled out" of the support surface. After sintering, the ceramic material is "lapped" to produce a relatively smooth support surface. Such lapping may fracture the support surface producing particles that adhere to and become trapped in pores on the support surface. These particles are difficult to completely remove from the support surface. Consequently, as the chuck is used, particles are continuously produced by these fractures. Additional particles are generated as the backside of the wafer scrapes the support surface. Empirical data shows that tens of thousands of contaminant particles may be found on the backside of a given wafer

after retention upon a ceramic electrostatic chuck. The term "sticking coefficient" is used to describe the characteristic of contaminant particles from the ceramic electrostatic chuck "sticking" to the wafer. The smaller the sticking coefficient, the lesser the likelihood of particle transfer.

Also, other contaminants, such as waste products from wafer processing (e.g., water), react with or form nucleation sites on the support surface causing additional contamination. Although, these process waste products are not considered principle contaminants, the cumulative buildup, after repeated processing and maintenance cycles, of these and all other contaminants with the conductive contaminant film, dramatically reduce chuck performance. Consequently, the chuck is rendered useless, i.e., the chucking force is severely degraded and/or non-uniform, which results in premature replacement of the chuck, thus, increasing unit cost and chamber downtime. Electrostatic chucks are also fabricated from other types of materials such as stainless steel. However, these other such materials sometimes suffer from the same contaminant build-up condition or are not always a viable alternative to ceramic-based electrostatic chucks.

Therefore, a need exists in the art for an apparatus and method that isolates the support surface of the ceramic chuck from the chamber atmosphere to prevent surface reaction with contaminants and preserve chuck performance and surface chemistry of the ceramic chuck and reduce the sticking coefficient of a ceramic chuck.

SUMMARY OF THE INVENTION

The disadvantages associated with the prior art are overcome by the present invention of an apparatus for protecting a substrate and a support surface of a substrate support chuck comprising a protective coating of a carbon-based material deposited upon the support surface. The protective coating may also contain silicon-based materials, such as for example a composite comprising carbon, oxygen,

silicon and hydrogen. The protective coating is approximately in the range of 1 - 5μm thick. The apparatus may also have a wafer spacing mask disposed upon the protective coating. Such wafer spacing mask further comprises a plurality of support members. The support surface and electrostatic chuck defining the support surface may be fabricated from ceramic, stainless steel, titanium alloys or metal matrix composites.

A method of fabricating a substrate support chuck is also disclosed and comprises the steps of forming a chuck body having support surface and depositing a carbon-based material over the support surface of said chuck body to form a protective coating. Optionally, a step of depositing a wafer spacing mask upon the protective coating may be added. The carbon-based material may also have a silicon-based material incorporated therein such as for example a composite comprising carbon, oxygen, silicon and hydrogen.

Using the protective coating of the present invention on the support surface of a chuck results in a substantial decrease in contamination of chucks, wafers and the process chamber environment. Specifically, the formerly exposed support surface of the chuck is sealed from the process chamber environment. As such, it cannot react with or otherwise grow conductive films. The protective coating exhibits an extremely low "sticking coefficient" (i.e., reduced surface friction) and increased surface hardness as to reduce the likelihood of depositing particles on the backside of a substrate supported by the electrostatic chuck. Additionally, the spaced apart relationship of the wafer relative to the coated support surface via the optional spacing mask ensures that particle counts from contaminants or grains from the support surface are greatly reduced. The protective coating does not significantly interfere with the clamping process or impact the clamping force that retains the wafer upon the electrostatic chuck. In this manner, contamination of the support surface of the chuck, the wafer and the process chamber are substantially reduced, while chuck performance is maintained.

BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawing, in which:

FIG. 1 depicts a vertical cross-section view of a ceramic electrostatic chuck containing the protective coating of the present invention supporting a semiconductor wafer;

FIG. 2 depicts a vertical cross-section view of a second embodiment of the subject invention having the protective coating and a wafer spacing mask;

FIG. 3 depicts a series of method steps for making the electrostatic chuck having the protective coating;

FIG. 4 depicts a fourth embodiment of the invention having a metal body with the protective coating thereupon;

FIG. 5 depicts a series of method steps for making the electrostatic chuck having the protective coating of the third embodiment; and

FIG. 6 depicts a third embodiment of the invention having a spacing mask of the protective coating material.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION

FIG. 1 depicts a vertical cross-sectional view of a ceramic electrostatic chuck 104 in accordance with the present invention. Such electrostatic chuck is used to retain and support a substrate, such as a semiconductor wafer, in a process chamber. Process chambers perform a variety of process steps upon the substrate (i.e., deposition by physical or chemical vapor means, etching, polishing and the like) to fabricate integrated circuits thereupon. Specifically, the chuck 104 has a protective coating 100 disposed atop a support surface 102. To illustrate the use of the invention, FIG. 1 also depicts a semiconductor wafer 112 supported by the chuck 104.

A feature of the invention is that the protective coating 100 be fabricated from a material that has properties that are different from the support surface materials and highly impervious to reaction with or formation of contaminants as discussed above. Specifically, the material of the protective coating 100 is such that the material does not react with contaminants thus, preventing formation of a conductive film on the ceramic chuck. Consequently, the support surface 102 of the chuck 104 is sealed from a usually harsh process chamber environment. Additionally, the support surface 102 of the chuck 104 does not contact a backside 114 of the wafer 112.

In an alternate embodiment of the invention depicted in FIG. 2, a ceramic electrostatic chuck 104 is provided with a wafer spacing mask 110. Specifically, the spacing mask 110 is disposed atop the protective coating 100 and comprises a plurality of individual support members 202 for maintaining the wafer 112 in a spaced apart relation to the support surface 102 and protective coating 100 of the electrostatic chuck 104. The support members 202 are positioned on top of the protective coating 100 in one embodiment of the invention. Alternately, the individual support members 202 are disposed upon the support surface 102 and the protective coating 100 is disposed over the individual support members 202 and unmasked portions of the support surface 102 to create a conformal layer having support regions (as defined by the support members 202 therebelow) . An illustrative ceramic electrostatic chuck containing such a wafer spacing mask is disclosed in commonly assigned U.S. Patent No. 5,656,093 issued August 12, 1997 and is herein incorporated by reference. In that disclosure, metallic material for the support members is deposited directly upon a support surface of an electrostatic chuck using a physical vapor deposition (PVD) process. The material may alternately be deposited using chemical vapor deposition (CVD) (thermal or plasma-enhanced), plasma spray deposition, flame spray deposition and the like. Likewise, these same deposition techniques

are available to deposit the support members 202 upon the protective coating 100 of the subject invention.

In a third embodiment of the invention depicted in FIG. 6., a ceramic electrostatic chuck 104 is provided having a spacing mask 610 disposed atop the wafer support surface 102. The spacing mask is similar to that disclosed in the above cited US Patent; however, the plurality of individual support members 202 is fabricated from the same material as the protective coating 100 of previous embodiments and as explained in greater detail below.

Generally, the electrostatic chuck also contains one or more electrodes 106 embedded within a ceramic chuck body 108. The electrodes 106 perform a variety of functions dependent upon placement within the chuck body 108, material used to form the electrode and power connection. Each electrode is provided with a connection to a power source via an electrical feed-through 116. Such electrical feed-throughs are seen and described in copending U.S. patent application serial no. 08/834,702 filed April 1, 1997 and is herein incorporated by reference. A bipolar chucking electrode configuration is depicted in FIG. 1 and in alternate embodiments seen in FIGS. 2 and 6 discussed in greater detail below. A pair of electrodes (106_1 and 106_2) is biased with equal and opposite polarity voltages to electrostatically clamp the wafer 112 to the chuck 104. Although a pair of side-by-side, bipolar electrodes is depicted, the electrode configuration may be any such configuration for clamping the wafer to the support surface including but not limited to monopolar, zonal bipolar (more than one set of bipolar electrodes) and the like. Additionally, electrodes may have various shapes including circular, interdigitated and the like. An additional electrode 106_3 is a resistive element (also connected to a power source, not shown) for raising the temperature of the electrostatic chuck 104 and wafer 112.

The ceramic chuck body 108 is, for example, fabricated of aluminum nitride or boron nitride. Such leaky dielectric material provides superior chucking force during high-

temperature processing of a semiconductor wafer. Other leaky dielectric materials (low resistivity) also form useful high temperature chuck materials such as alumina doped with titanium-oxide or chromium-oxide. If the chuck is to be used at low temperatures only, then other ceramic and/or dielectric materials such as alumina are used to form the chuck body.

To facilitate heat transfer from the wafer 112 to the chuck body 108, a heat transfer medium, e.g., a gas such as Argon, is pumped into interstitial spaces 124 between the backside 114 of the wafer 112 and the protective coating 100 or mask 610. This thermal coupling technique is used for either heating or cooling wafers depending on the specific process that the wafers are undergoing. The heat transfer medium is provided to the backside 114 of the wafer 112 via a port 118 that is formed through the chuck body 108 and the protective coating 100 or mask 610. The medium is typically supplied to the backside 114 of the wafer 112 by a remote source (not shown) at a rate of approximately 2 to 30 sccm. Such backside cooling is well known in the art and is disclosed, for example, in commonly assigned U.S. Patent 5,228,501 issued to Tepman, et al., on July 20, 1993.

A plurality of heat transfer medium distribution channels 120 may be formed in the chuck 104 to aid distribution of the heat transfer medium across the backside 114 of the wafer 112. The channels are typically cut into the support surface 102 of the chuck body 108 and the protective coating 100 conformally coats the support surface 102 to yield a plurality of conformal channels 122 in the protective coating 100.

Prior to applying the protective coating 100, the chuck 104 is cleaned by either a plasma or sputter etch process. Then, the protective coating 100 is deposited upon the support surface 102 of the chuck body 108 typically by plasma-enhanced chemical vapor deposition (CVD) of a carbon-based nano-composite further comprising a silicon-based material. A thermal CVD process may also be performed in lieu of the plasma-enhanced process. Specifically, the

protective coating 100 forms a carbon lattice structure (similar to that of diamond) which has high mechanical strength and resistance to chemical and electrical breakdown. The silicon-based material provides the protective coating with stable resistivity throughout the operational temperature range of the chuck 104 (typically from room temperature to about 550°C). An example of a suitable coating material is a silicon-carbon composite material having the brand name DLN. DLN is manufactured and sold by Advanced Refractory Technologies, Inc. of Buffalo, New York. The protective coating 100 is evenly and conformally deposited across the entire support surface 102 of the chuck body 108 in the embodiments shown in FIGs. 1 and 2. Other deposition techniques include sputtering, flame spraying and the like. For example, deposition is performed through a stencil to create the spacing mask shown in the embodiment in FIG. 6. The material of the protective coating (or alternate spacing mask) has a superior non-reactive property as compared to the support surface material of the chuck. This material prevents adsorption or reaction of the support surface 102 with contaminants in the atmosphere and is stable in a vacuum environment such as in a process chamber in which the electrostatic chuck 104 is used. Additionally, the coating material is generally less abrasive and more compliant (e.g., produces less particles) than the support surface material. After the protective coating 100 is deposited upon the support surface 102, material to form the support members of the spacing mask is deposited atop the coating 100 when fabricating an electrostatic chuck in accordance with FIG. 2.

When the protective coating 100 is deposited as a thin layer using the above-mentioned DLN material, it will have a thickness of, for example, approximately 1-5μm. Such material, when thinly deposited does not require lapping nor sintering and, as such, is not fractured or porous. Additionally, a surface created by such coating does not react with hydrocarbons and other such contaminants. The thickness of the protective coating 100 does not interfere

or severely reduce the chucking force and facilitates conformal coating over the channels 120 in the support surface 102. For example, in a chuck using the Johnsen-Rahbek effect, charges, influenced by the potential difference between the electrodes 106, migrate through the leaky dielectric material of the chuck body 108. Dependent upon the resistivity, of the coating 100, the charges also migrate therethrough. As such, a leakage current is formed that conducts to the backside 114 of the wafer 112. Typically, the resistivity of the coating should be approximately 10^8-$10^{12}\Omega\cdot$cm or higher to create the desired results. This value can be altered as necessary by a separate conductive material sputtering step. That is, a conductive material (i.e., aluminum or titanium) is sputtered into the protective coating 100 to alter its resistivity. It should be noted that the dimensions of the protective coating 100 and channels 120 have been greatly exaggerated for easy viewing and understanding of the invention. Typically, the channels 120 formed in the chuck body 108 are approximately 50μm deep. As discussed, the protective coating 100 is approximately 1-5μm thick. As such, when the protective coating is at its thinnest (~50Å) the channels 120 are approximately 5 x 10^5 deeper than the protective coating 100 is thick.

FIG. 3 depicts a series of method steps 300 for fabricating the electrostatic chuck 104 having the protective coating 100. The method starts at step 302 and proceeds to step 304 wherein the chuck body is formed and feed-throughs and electrodes are disposed within the chuck body. Typically the chuck body is comprised of a plurality of uncured, insulating material layers such as aluminum nitride in an unsintered, green-body state. The layers are stacked on top of each other and interleaved with a conductive material to form the embedded electrodes. Feed-through holes are punched through the required insulating layers to contact the conductive material and prefilled with a conductive material which, after sintering, forms the

metallized feed-through. At step 306, the unsintered material is then sintered, i.e., subjected to a high temperature and pressure, to form a cured solid chuck body. At step 308, the electrostatic chuck is provided with a protective coating as discussed above. Specifically, a chemical vapor deposition step is performed wherein the carbon containing film is deposited over a top surface of the chuck body. A preferred thickness for the coating is between 1 and 5 microns. The method ends at step 310 wherein a completely formed electrostatic chuck having a protective coating is now available for use (assembly into a process chamber).

FIG. 4 depicts a fourth embodiment of the invention of electrostatic chuck 104 having a protective coating 404 thereupon. Specifically, in this embodiment the chuck body 108 is fabricated from a durable material such as those selected from the group consisting of stainless steel, titanium alloys and metal matrix materials such as AlSiC and TiSiC. An intermediate coating 402 is disposed upon the top surface 102 of the chuck body 108. The intermediate coating 402 is a typical dielectric material or alternately the nano-composite, diamond-like material (i.e., DLN) of which coating 100 of FIG. 1 is comprised. One or more electrodes 106 are disposed upon the intermediate coating 402 and connected to appropriate feed-throughs 116 which extend through and are insulated from the body 108. The feed-throughs are formed typically by conventional techniques such as drilling or laser cutting. If the metal matrix material is used, inserts for the feed-throughs may be placed in a blank prior to injection molding of the material. The protective coating 404 is disposed upon the electrodes 106 (and any exposed portion of the intermediate coating 402) to totally seal the top surface 102 of the chuck body 108. The protective coating is fabricated from the nano-composite, diamond-like material (i.e., DLN).

A method for forming the electrostatic chuck 104 of this second alternate embodiment is depicted in FIG. 5. Specifically, a series of method steps 500 begins at step

502 and proceeds to step 504 wherein the electrostatic chuck body 108 is formed from a durable material (for example a stainless steel platen) with appropriate bores provided in the platen for electrical feed-throughs (wires). At step 506 an insulator material is deposited upon the chuck body to form an intermediate layer. Such insulator material includes the material of the protective coating discussed earlier (i.e., the carbon containing film). At step 508 a metal deposition step is used to deposit one or more electrodes on top of the insulator film (intermediate coating). The electrodes are formed by any of the known methods of those skilled in the art of substrate support fabrication and include but are not limited to physical vapor deposition, chemical vapor deposition, electroplating, or the like. Step 508 results in a portion of the top of the chuck body still being exposed along with exposed metallized electrodes. At step 510 these exposed portions of the electrostatic chuck are provided with a protective coating as discussed above. Specifically, a chemical vapor deposition step is performed wherein the carbon containing film is deposited over the electrodes and the chuck body. As discussed earlier a preferred thickness for the coating is between 1 and 5 microns. The method ends at step 512 wherein a completely formed electrostatic chuck having a protective coating is now available for use (assembly into a process chamber).

Using the protective coating of the present invention on the support surface of a chuck results in a substantial decrease in contamination of chucks, wafers and the process chamber environment. The protective coating reduces wear of the support surface and its static coefficient of friction thereby reducing particle generation from the backside of the wafer. Naturally occurring contaminants that would form a conductive film are substantially reduced. As such, the need to clean the support surface (i.e., by a sputter etch conditioning or similar maintenance step) is eliminated. Thus, downtime associated with reconditioning a poorly performing chuck is substantially reduced. Importantly, the

protective coating provides these advantages but does not significantly interfere with the clamping process or impact the clamping force that retains the wafer upon the electrostatic chuck.

Although various embodiments which incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.

What is claimed is:

1. Apparatus for protecting a substrate and a support surface of a ceramic substrate support chuck comprising:
a protective coating, deposited upon the support surface, said protective coating comprising a carbon-based material.

2. The apparatus of claim 1 wherein said protective coating further comprises carbon-based and silicon-based materials.

3. The apparatus of claim 2 wherein said protective coating is a diamond-like nano-composite.

4. The apparatus of claim 1 wherein the protective coating is deposited via plasma-enhanced CVD.

5. The apparatus of claim 1 wherein the protective coating is approximately in the range of 1 - 5μm thick.

6. The apparatus of claim 1 wherein a wafer spacing mask is disposed upon the support surface and the protective coating is disposed over the mask and unmasked portions of the support surface.

7. The apparatus of claim 1 wherein the protective coating is in the form of a wafer spacing mask.

8. The apparatus of claim 1 further comprising a wafer spacing mask disposed upon the protective coating.

9. The apparatus of claim 8 wherein the wafer spacing mask further comprises a plurality of support members.

10. Apparatus for supporting a workpiece comprising:
a ceramic electrostatic chuck having a plurality of electrodes embedded beneath a support surface; and

a carbon-based protective coating, disposed upon said support surface of said ceramic electrostatic chuck.

11. The apparatus of claim 10 wherein said protective coating further comprises carbon-based and silicon-based materials.

12. The apparatus of claim 11 wherein said protective coating is a diamond-like nano-composite.

13. The apparatus of claim 11 wherein the protective coating is deposited via a plasma-enhanced CVD.

14. The apparatus of claim 10 wherein the protective coating is approximately in the range of 1 - 5μm thick.

15. The apparatus of claim 10 wherein a wafer spacing mask is disposed upon the support surface and the protective coating is disposed over the mask and unmasked portions of the support surface.

16. The apparatus of claim 10 wherein the protective coating is in the form of a wafer spacing mask.

17. The apparatus of claim 10 further comprising a wafer spacing mask disposed upon the protective coating.

18. The apparatus of claim 17 wherein the wafer spacing mask further comprises a plurality of support members.

19. A method of fabricating a substrate support chuck comprising the steps of:

forming a ceramic chuck body having support surface; and

depositing a carbon-based material over the support surface of said chuck body to form a protective coating; and

depositing a wafer spacing mask upon the protective coating.

20. The method of claim 19 further comprising the step of depositing a wafer spacing mask upon the protective coating.

21. The method of claim 19 wherein said carbon-based material further comprises a silicon-based material.

22. The method of claim 19 wherein said carbon-based material is a diamond-like nano-composite.

23. The method of claim 19 wherein the step of depositing the protective coating is performed via a plasma-enhanced CVD.

24. The method of claim 19 wherein the protective coating is approximately in the range of 1 - 5μm thick.

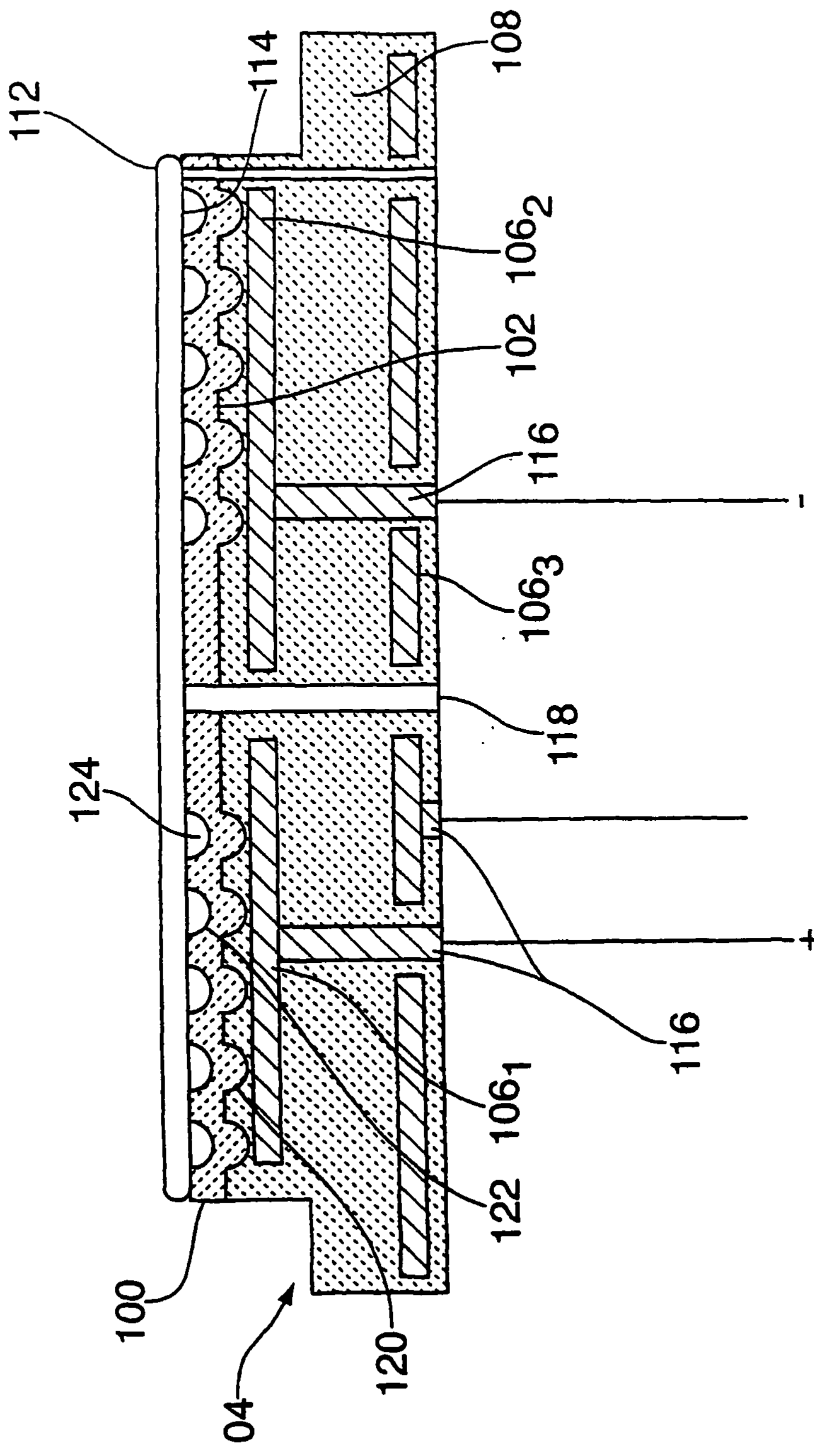

FIG. 1

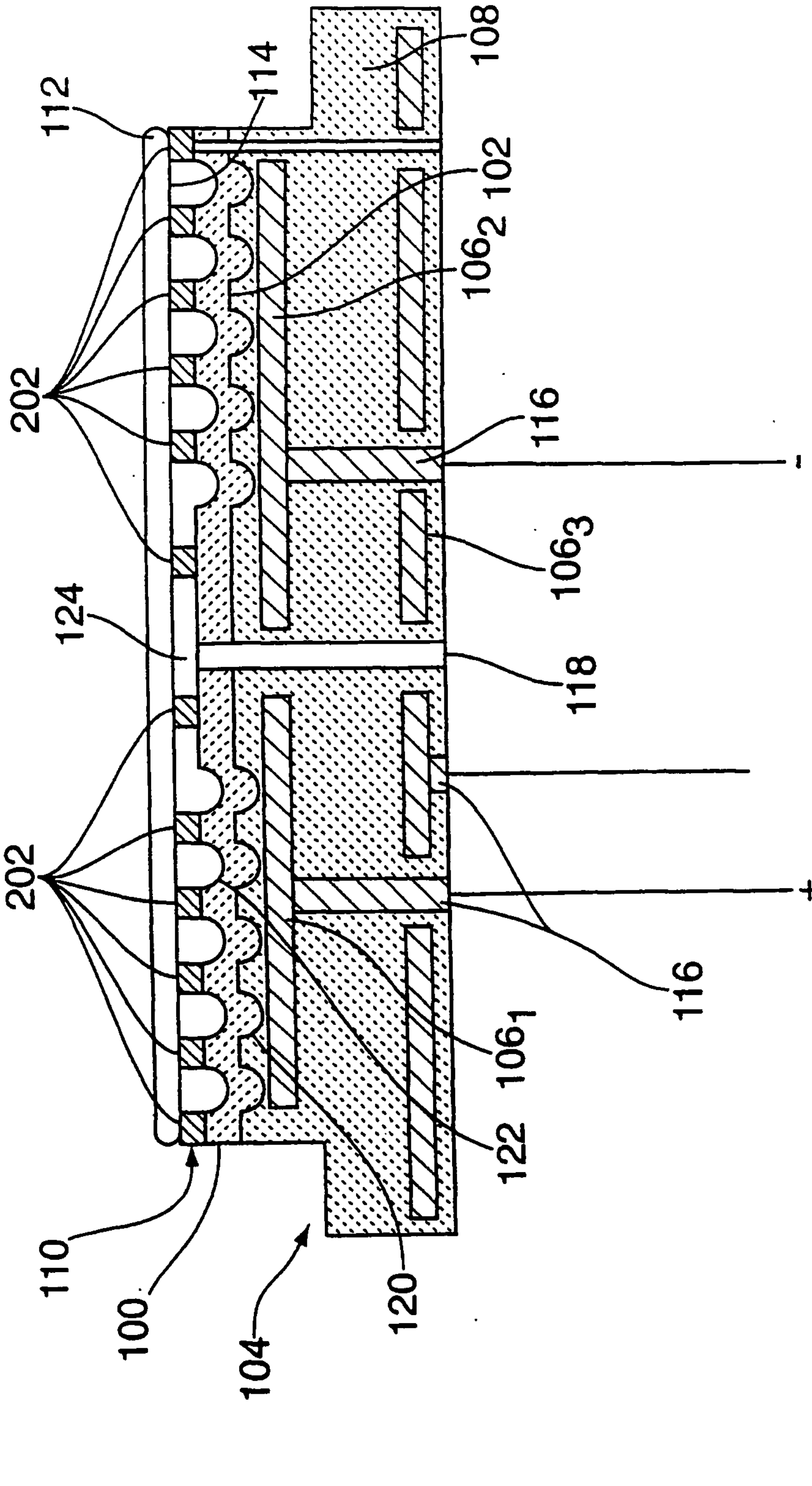
112
114
108
102
106_2
202
116
-
106_3
124
118
202
+
116
106_1
122
120
110
100
104

FIG. 2

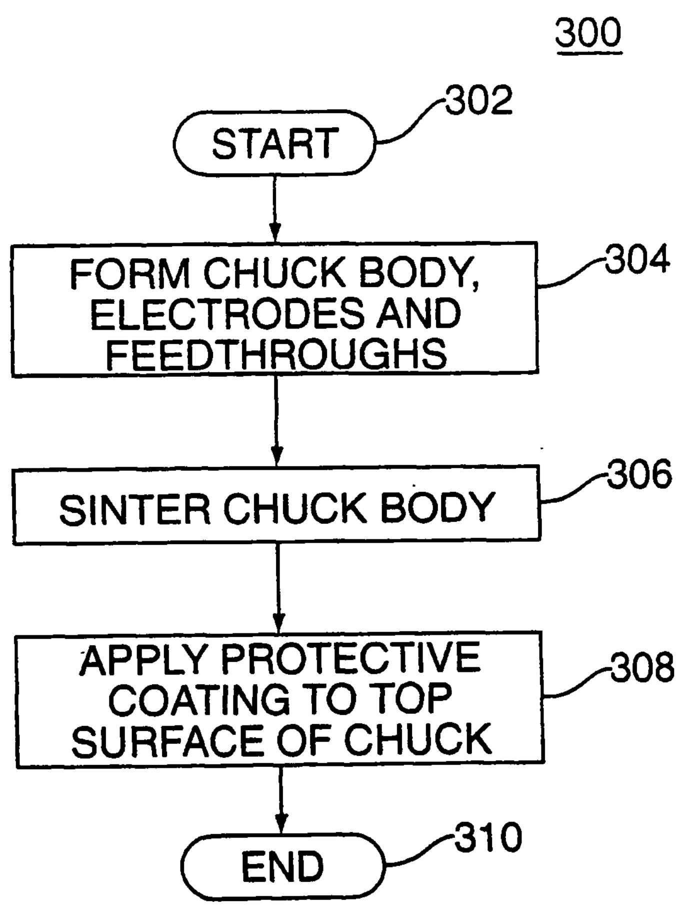
300
302
START
304
FORM CHUCK BODY, ELECTRODES AND FEEDTHROUGHS
306
SINTER CHUCK BODY
308
APPLY PROTECTIVE COATING TO TOP SURFACE OF CHUCK
310
END

FIG. 3

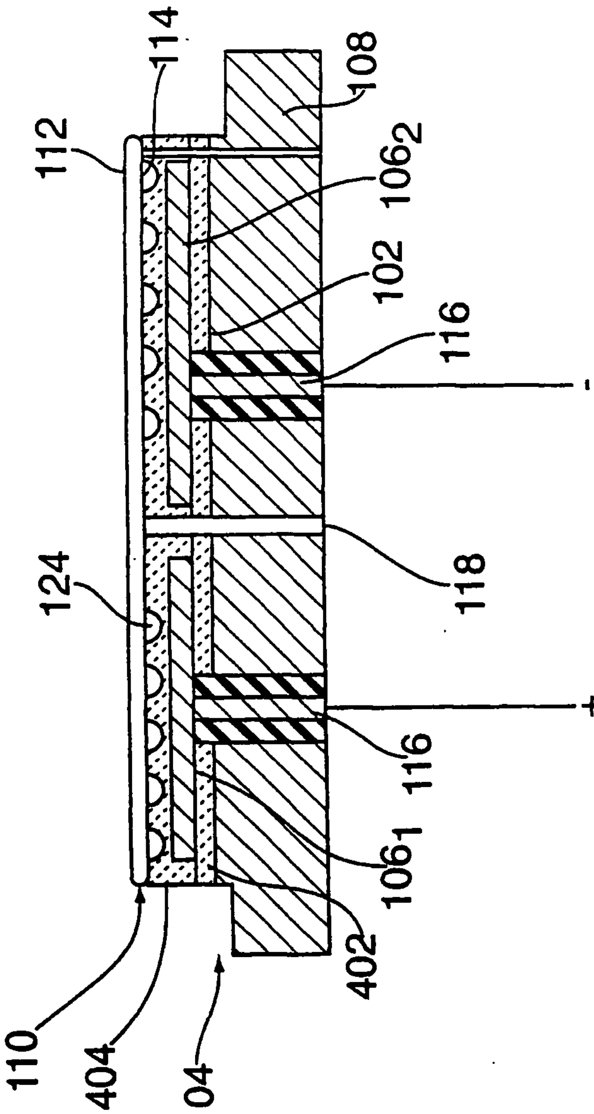

FIG. 4

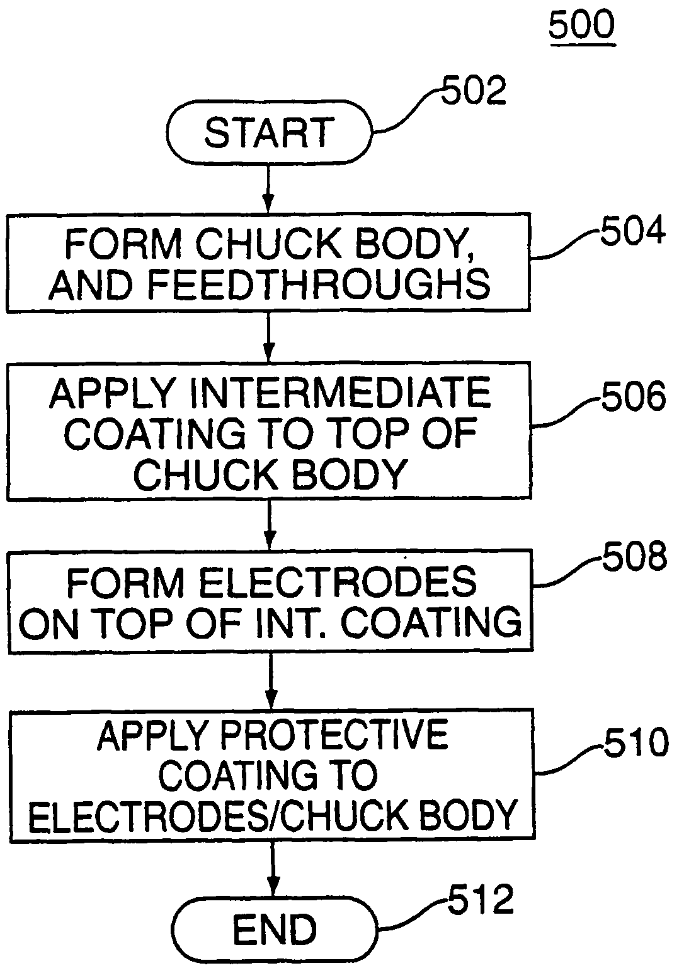
500
START
502
FORM CHUCK BODY, AND FEEDTHROUGHS
504
APPLY INTERMEDIATE COATING TO TOP OF CHUCK BODY
506
FORM ELECTRODES ON TOP OF INT. COATING
508
APPLY PROTECTIVE COATING TO ELECTRODES/CHUCK BODY
510
END
512

FIG. 5

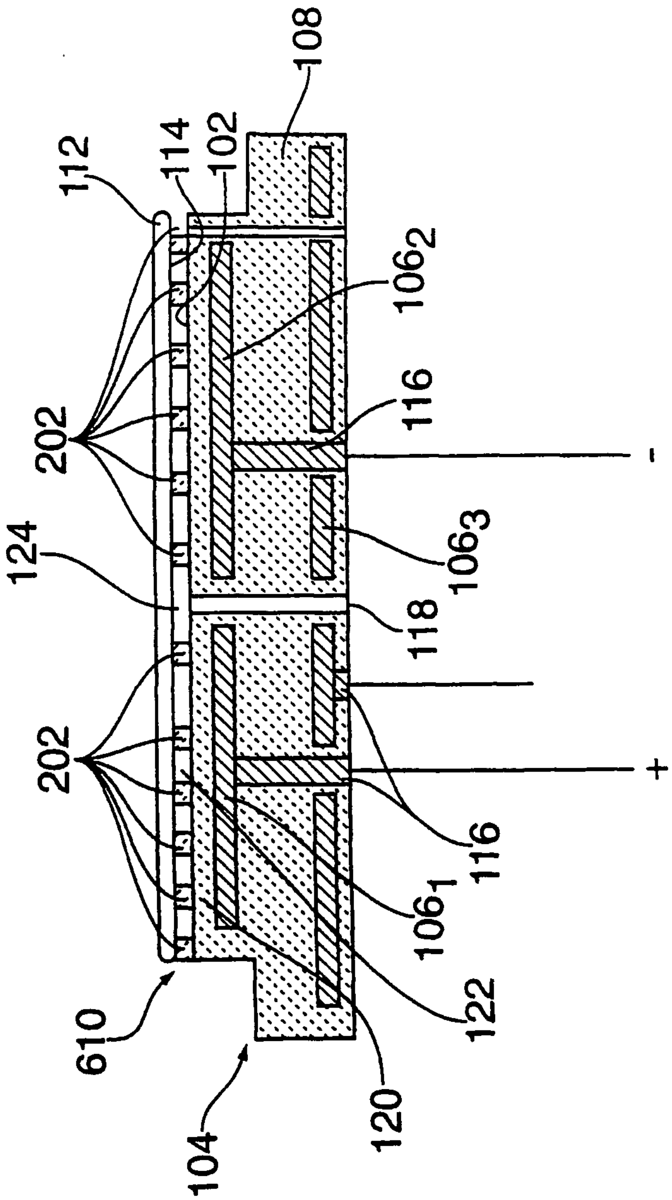
108
112
114
102
106_2
116
202
124
106_3
118
202
116
106_1
122
610
104
120
-
+

FIG. 6